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# **Anomaly Trends for Missions to Mars: Mars Global Surveyor and Mars Odyssey**

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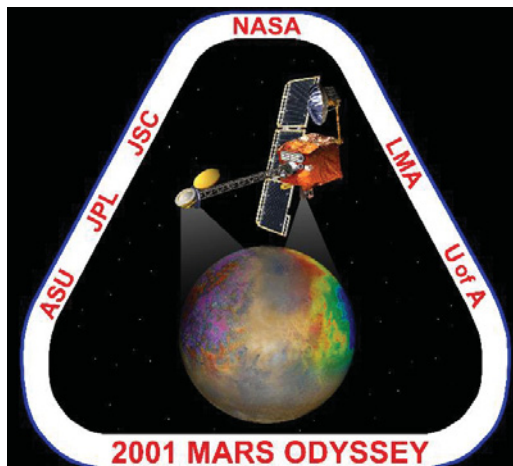
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## Topics



- Objectives
- Anomalies by Time
  - Mars Global Surveyor
  - Mars Odyssey
- Anomalies by Type
  - Anomaly Sources
  - Corrective Actions
- Conclusions





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## Objectives

- **Conducted as a part of NASA Ultra-Reliability effort**
  - Goal is to design for increased reliability in all NASA missions
  - Desire is to increase reliability by a factor of 10
  - Study provides a baseline for current technology
- **Analyzed anomalies for spacecraft orbiting Mars**
  - Long lived spacecraft
  - Comparison with current rover missions and past orbiters
- **Looked for trends to assist design of future missions**
  - How many anomalies?
  - When did they occur?
  - Where did they coming from?
  - What kinds of responses?

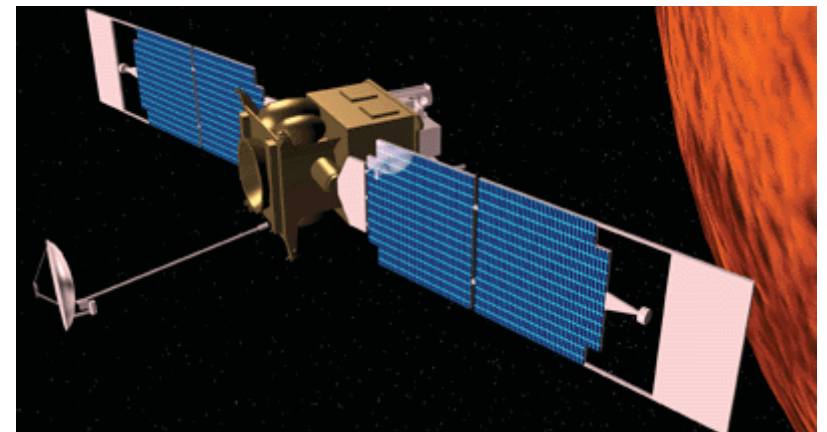
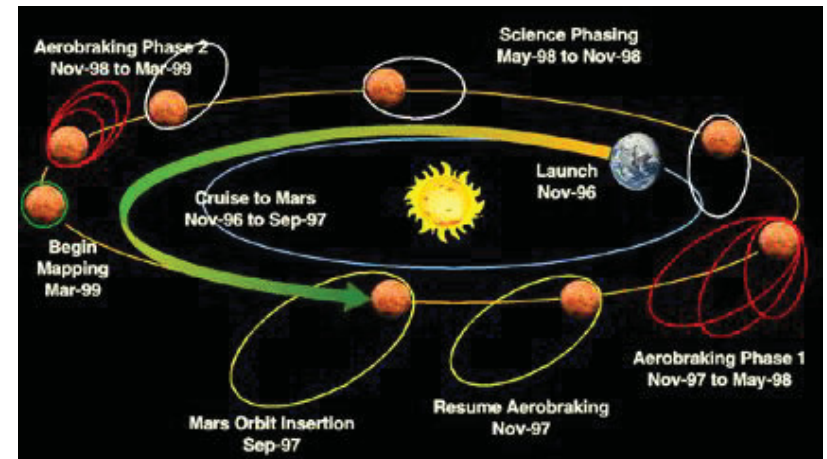


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# Mars Global Surveyor



- Launched 7 November 1996
- Mars Orbit Insertion 11 September 1997
- Second use of Aerobraking to get to final science orbit
  - Sept 1997 to Oct 1997
  - Nov 1997 to May 1998
  - Sept 1998 to Feb 1999
- Mapping of surface began in April 1999
- Primary mission completed in January 2001
- Extended mission through November 2006 when the spacecraft was lost



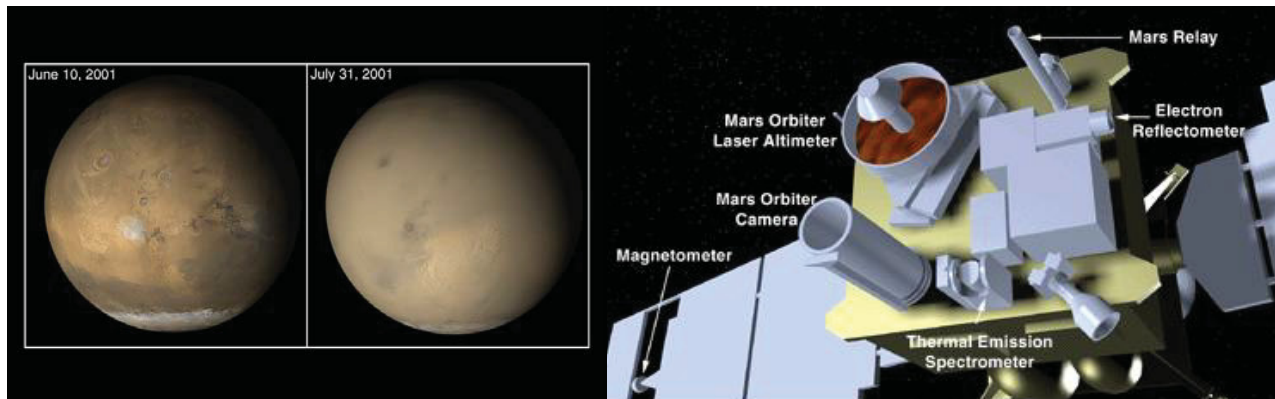
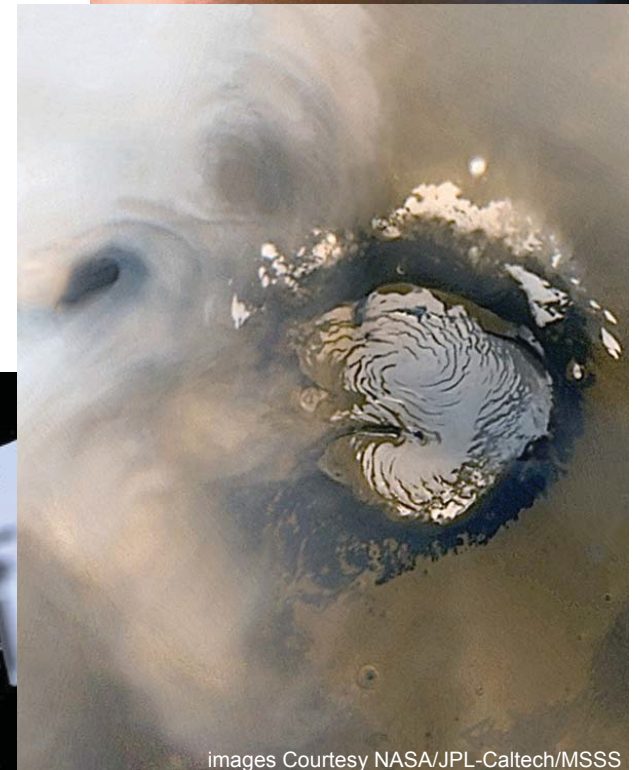




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# Mars Global Surveyor

- **MGs was a return to Mars after loss of Mars Observer in 1992**
  - Six primary instruments
  - Several came from MO project
- **Spacecraft constructed and operated by Lockheed Martin**
  - Oversight for NASA provided by JPL
- **An example of a very successful mission long life mission**
  - Ten years of operation



images Courtesy NASA/JPL-Caltech/MSSS



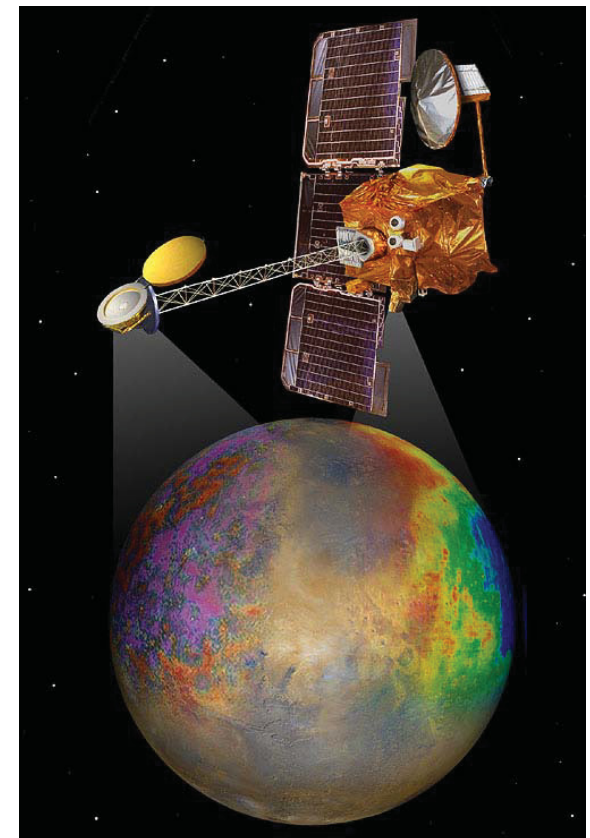
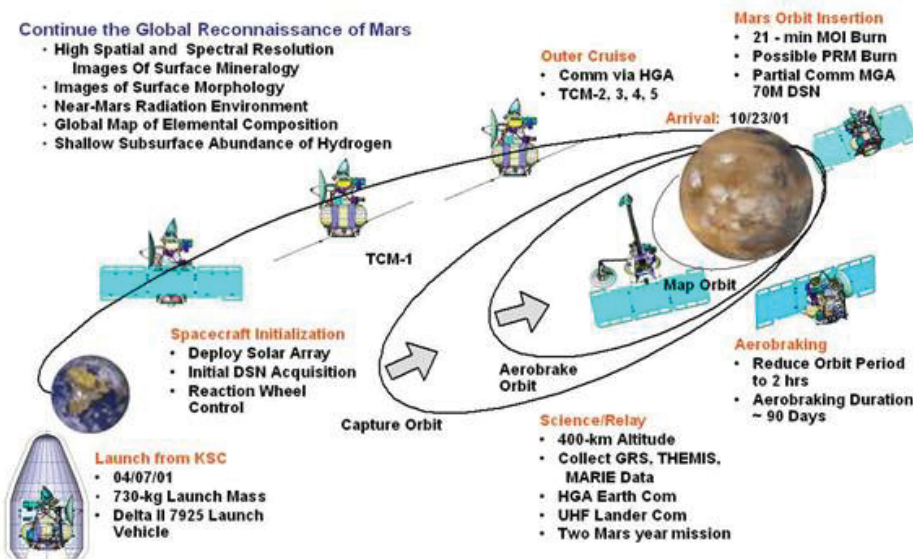
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# Mars Odyssey



- Launched on 7 April 2001
- Mars Orbit Insertion on 24 October 2001
- Aerobraking utilized to achieve final science orbit
  - Completed in January 2002
- Primary mission February 2002 to August 2004
- Extended mission begun in August 2004

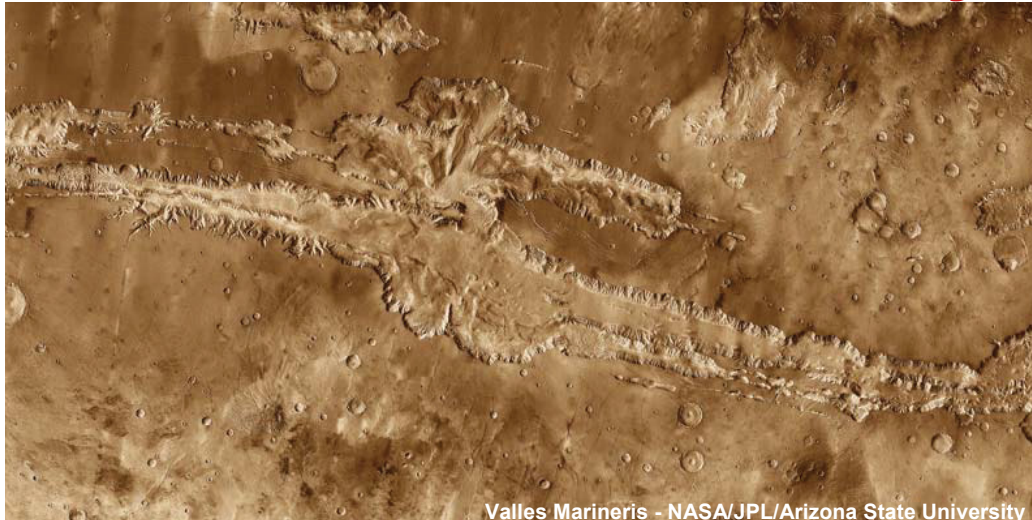




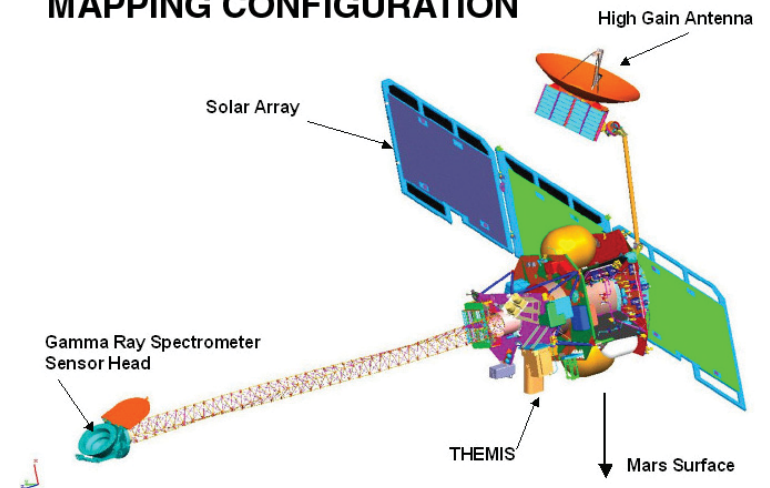
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# Mars Odyssey



## MAPPING CONFIGURATION



- **Spacecraft built and operated by Lockheed Martin**
  - Oversight for NASA by JPL
- **Three primary science instruments**
  - Several secondary instruments
- **Return to Mars after loss of MCO and MPL**
- **Serves as primary relay for Mars Exploration Rovers**





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## **In-flight Anomaly Reporting**

- **Incident Surprise Anomaly (ISA) Reports**
- **Document anomalies on spacecraft or ground support system during operations**
  - **Process**
    - **Problem described**
    - **Verification**
    - **Corrective Action Taken**
    - **Review and Approval**
    - **Closure**
- **1160 Mars Global Surveyor ISAs evaluated**
- **536 Mars Odyssey ISA evaluated**





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## Anomalies by Time

- **Anomalies were plotted as a function of time**
  - Units were number of anomalies per month
  - All anomalies counted
    - No preference given for criticality
    - Ground and Flight based anomalies grouped together
- **Key trends from plots**
  - Months with the most anomalies at beginning of mission
  - Key milestones often have peaks in anomaly reporting
  - Decreasing numbers of anomaly reports with increasing mission time

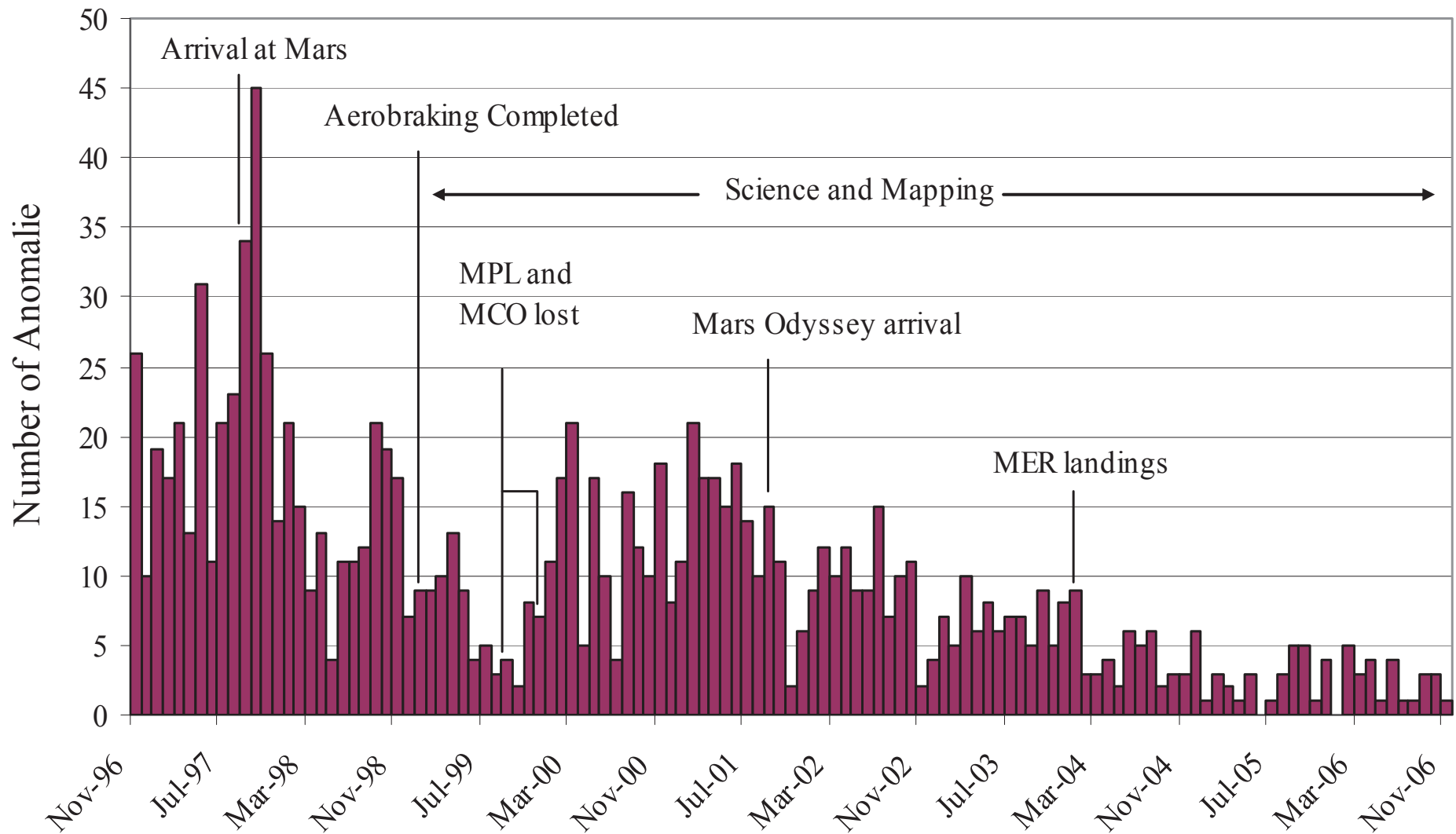


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## Anomalies by Time - MGS



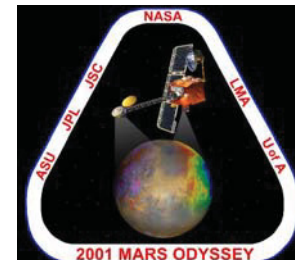
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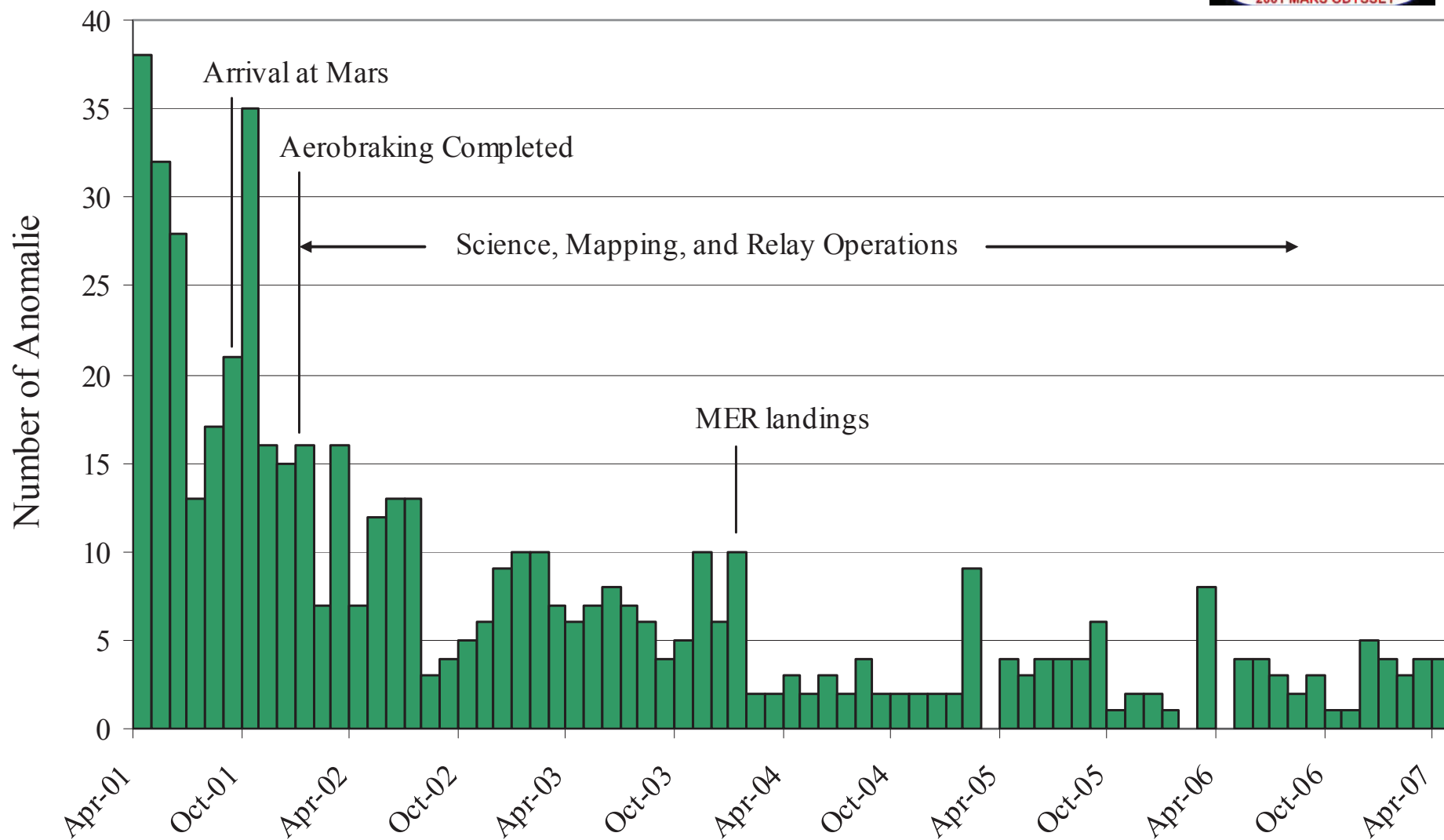


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## Anomalies by Time - Odyssey



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## Anomalies by Time

- Trends identified can be seen for both missions
- MGS
  - Peak early in mission is less prominent
  - Localized peaks not as closely tied to spacecraft activity
    - May be due to ground bases issues
  - Large low region during Faster, Better, Cheaper paradigm
- Odyssey
  - Majority of anomalies occurred early in mission
  - Peaks with mission activity
- Overall decrease in anomaly reports with time
- Compares well with other missions previously examined
  - Next few slides show examples

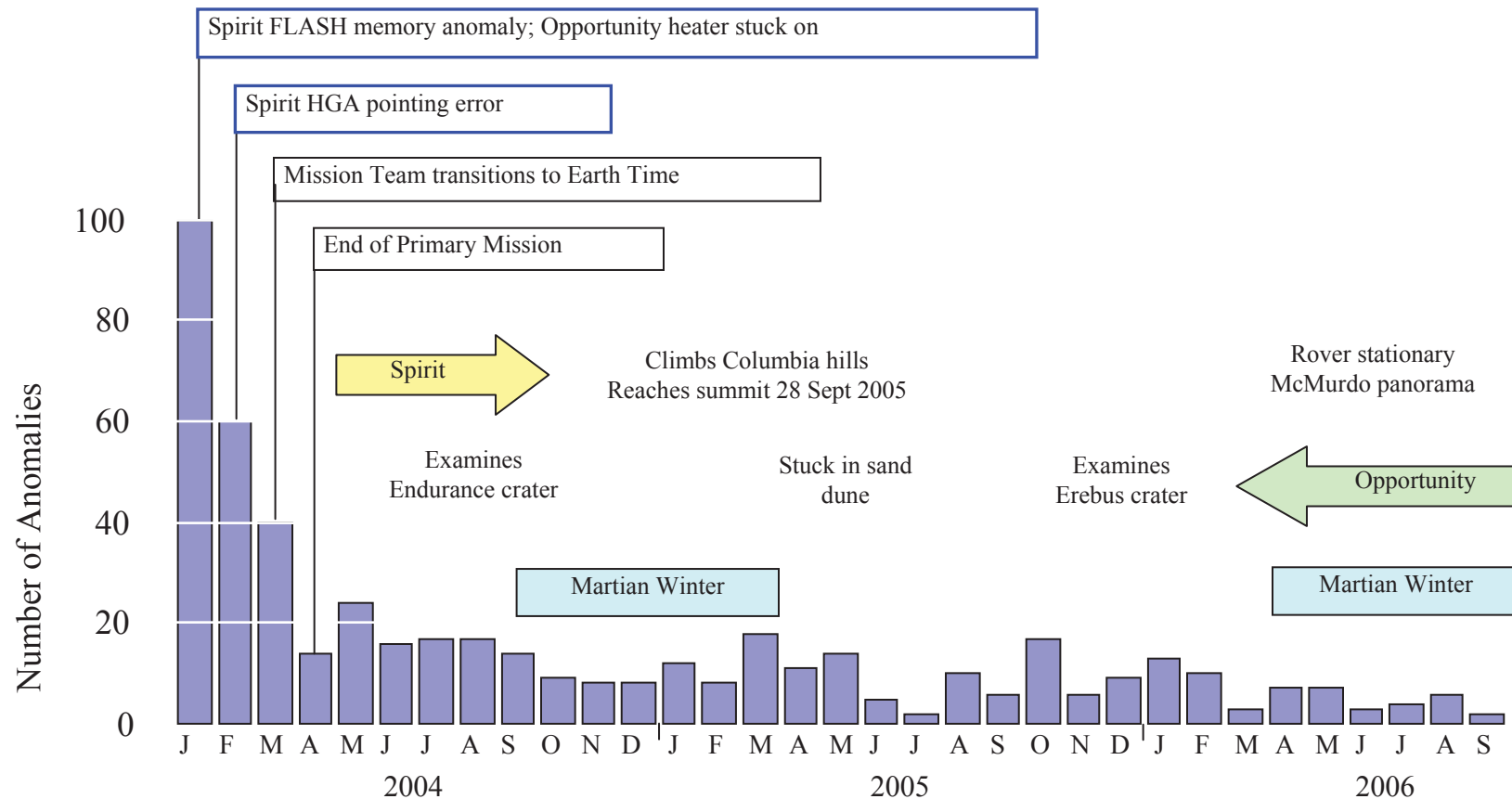




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## Anomalies by Time – MER



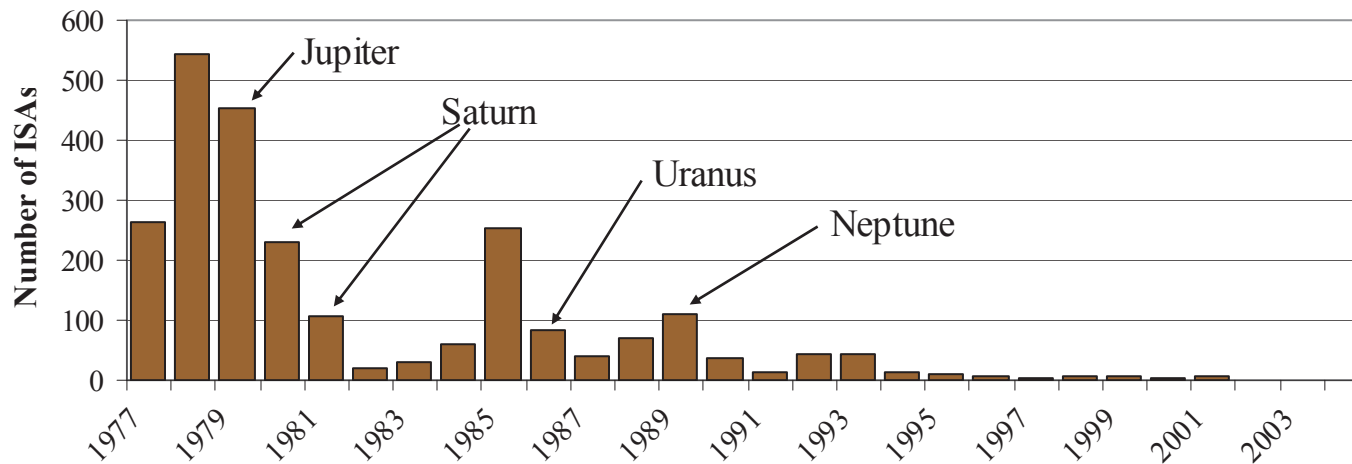


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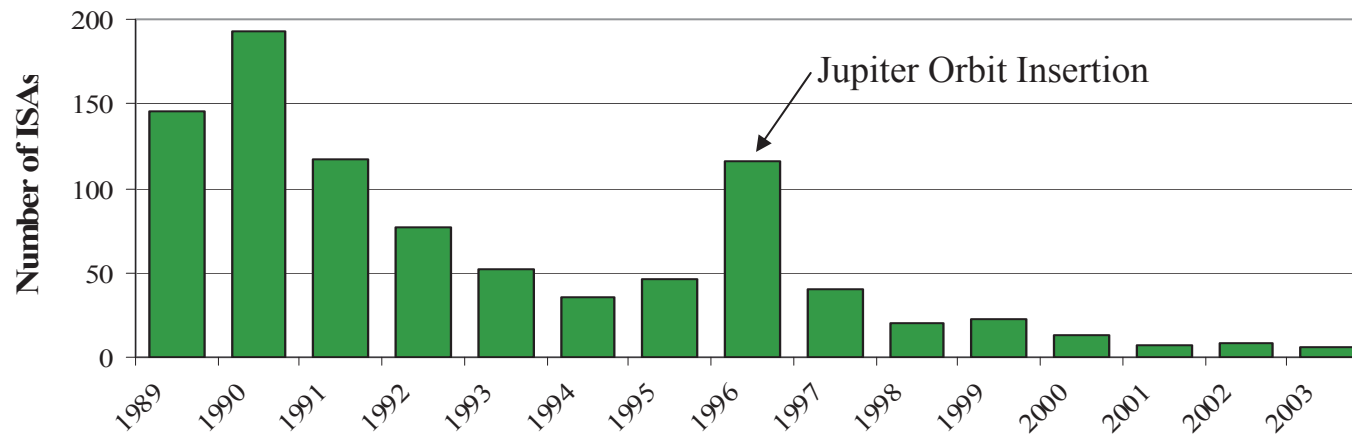
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# Anomalies by Time – Voyager and Galileo

Voyager - ISA Quantities by Year



Galileo -Quantities by Year





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## Anomalies by Time

- **Trends seen on MGS and Odyssey are typical**
  - Large numbers of anomalies at beginning
    - Mission team learning to operate spacecraft
    - New ground control equipment
    - New software to work out
  - Peaks at periods of high activity
    - More emphasis given to spacecraft at that time
    - Systems reactivated if dormant
    - Increased activity = More anomalies seen
  - Number of anomaly reports decreases with increasing mission time
    - More familiarity with spacecraft and ground systems
    - Many bugs have been worked out
    - Smaller mission teams



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## Anomalies by Type

- **Database of ISA reports created for both MGS and Odyssey**
  - MGS: 1160 ISAs
  - Odyssey: 536 ISAs
- **Each anomaly individually reviewed and characterized**
- **The description of event was used to determine the source of the anomaly**
  - Five generalized anomaly sources identified
  - Followed pattern of previous parts of this study
- **Examined real-time and overall corrective actions to determine mission team response**
  - Five generalized corrective actions used
  - Incomplete (open) reports labeled “Unknown”





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## Anomaly Sources

- **Flight Hardware**
  - Spacecraft component anomaly or failure
- **Ground Hardware**
  - Mission Control or Deep Space Network facilities
- **Flight Software**
  - Software event on board spacecraft
- **Ground Software**
  - Software event on Earth based computers
- **Procedure**
  - Improper procedure
  - Lack of prior knowledge

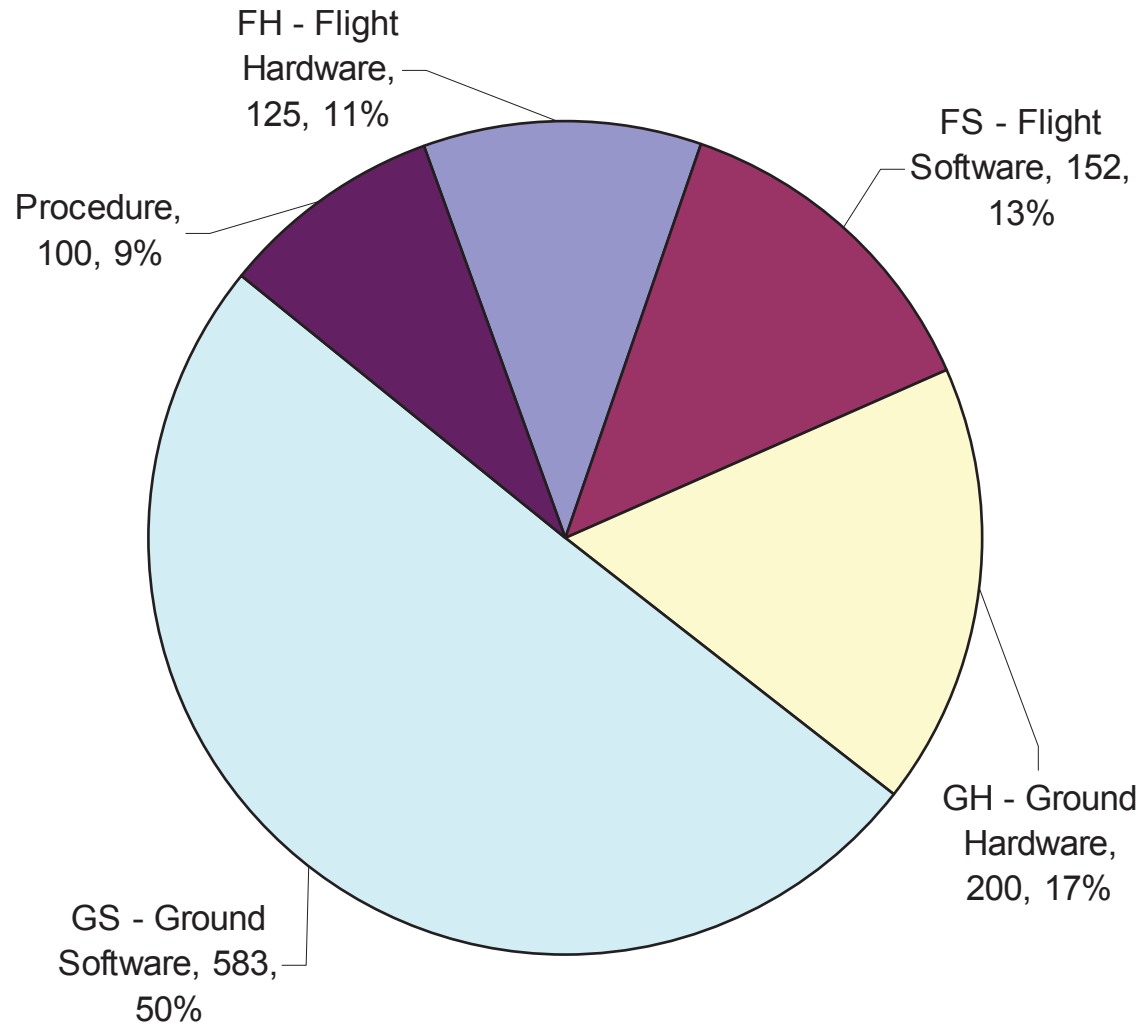


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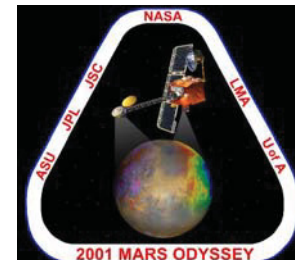
## Anomalies Sources - MGS



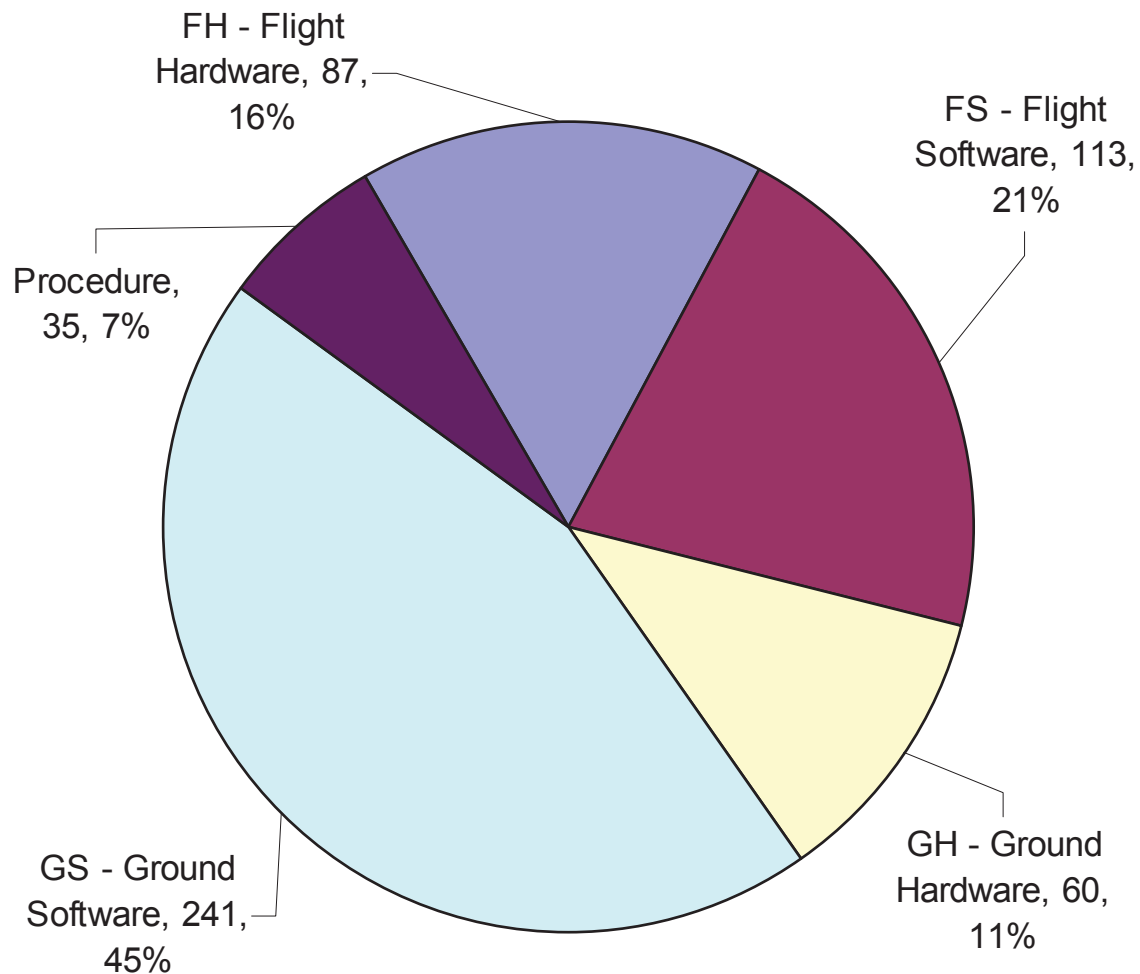


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## Anomalies Sources - Odyssey

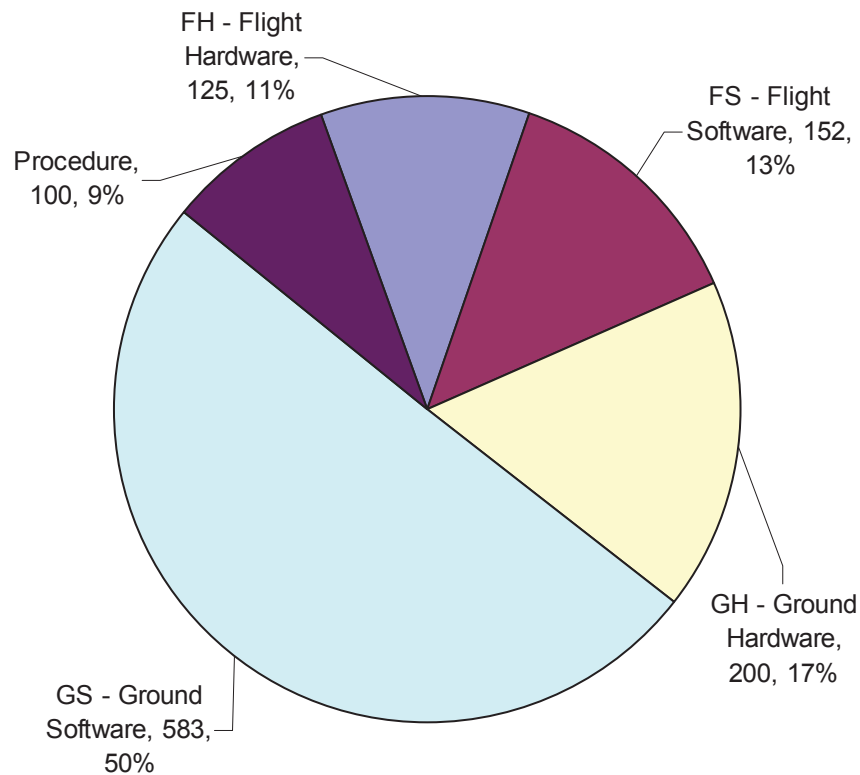




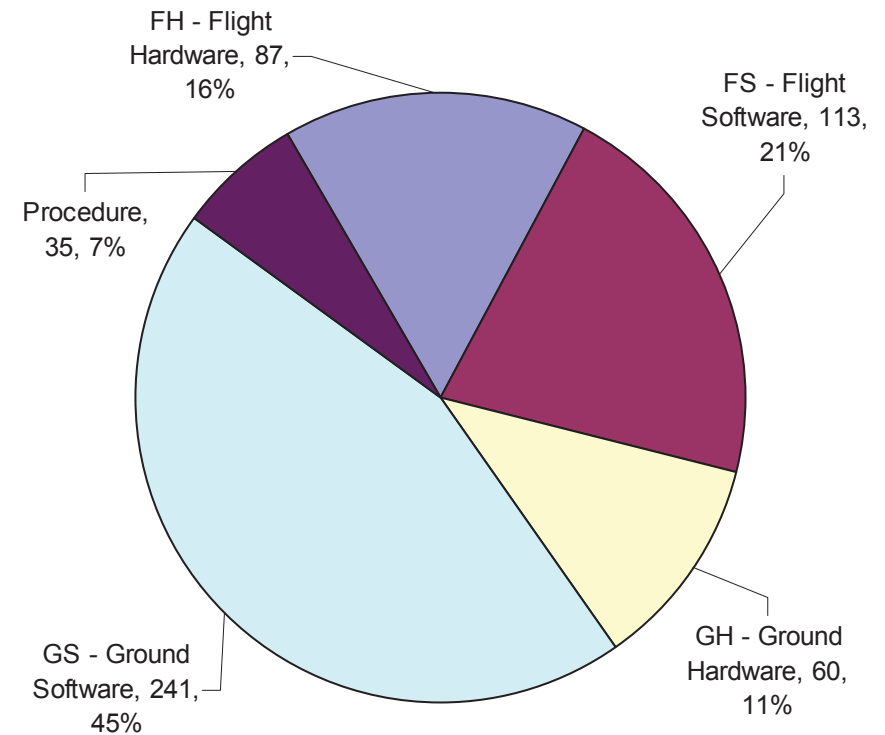
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## Anomalies Sources



Mars Global Surveyor  
1996 – 2006 : 1160 ISAs



Mars Odyssey  
2001 – April 2007 : 536 ISAs





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## Anomaly Sources

- **Ground based anomalies represent  $\frac{2}{3}$  to  $\frac{3}{4}$  of all anomalies for both missions**
- **Ground Software anomalies are most prevalent**
  - Control sequence generation issues
  - Data processing / storage issues
  - Ground support software
  - Login errors
- **Ground Hardware anomalies were less dominate**
  - More common on MGS
    - Issues with DSN hardware
    - Lockheed to JPL connection issues
- **Procedure issues least common**



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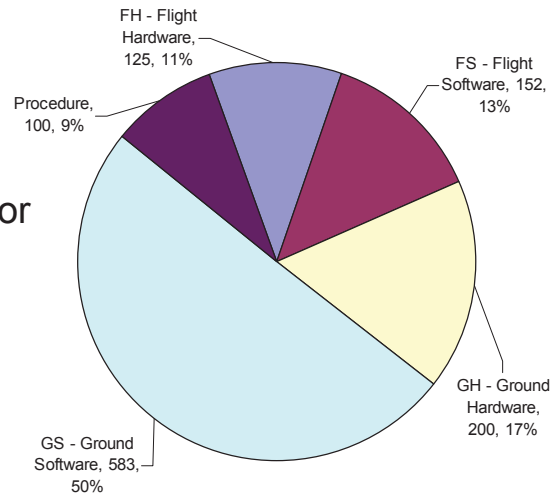
## Anomaly Sources

- **Flight based anomalies represent  $\frac{1}{4}$  to  $\frac{1}{3}$  of all anomalies**
- **Fairly equal balance for both missions**
  - **Flight Hardware**
    - **MGS: 11%**
    - **Odyssey: 16%**
  - **Flight Software**
    - **MGS: 13%**
    - **Odyssey: 21%**
- **These results are similar to other recent missions analyzed, but differ from earlier missions**

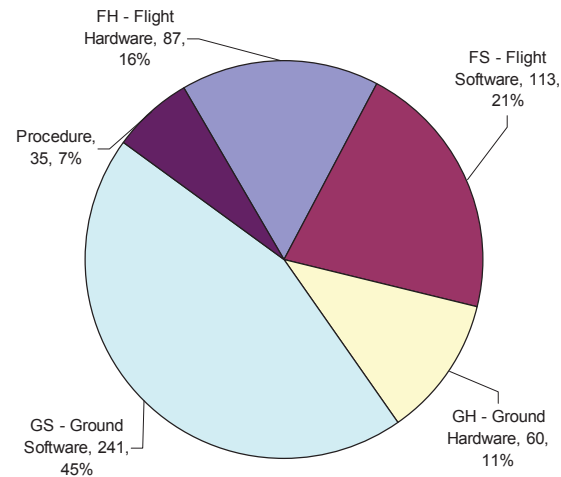


# Anomaly Sources

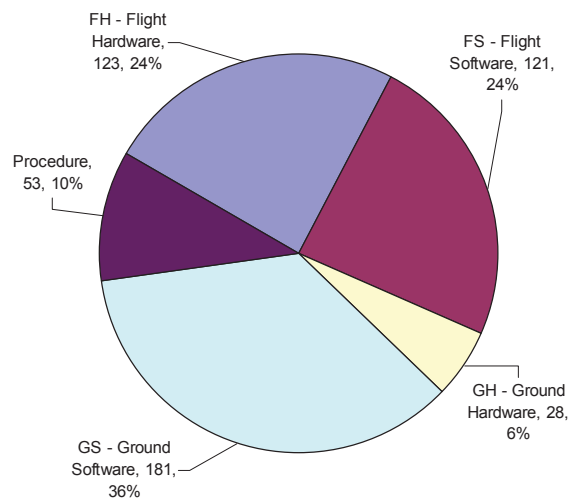
Mars Global Surveyor  
1996 – 2006  
1160 ISAs



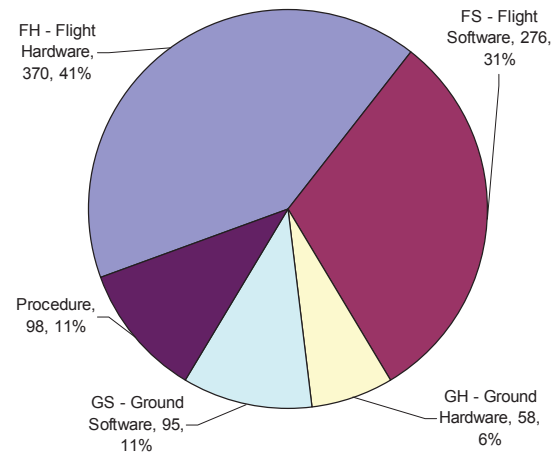
Mars Odyssey  
2001 – April 2007  
536 ISAs



MER  
Surface Ops  
2004 – Aug 2006  
506 ISAs



Galileo  
1989 – 2003  
897 ISAs



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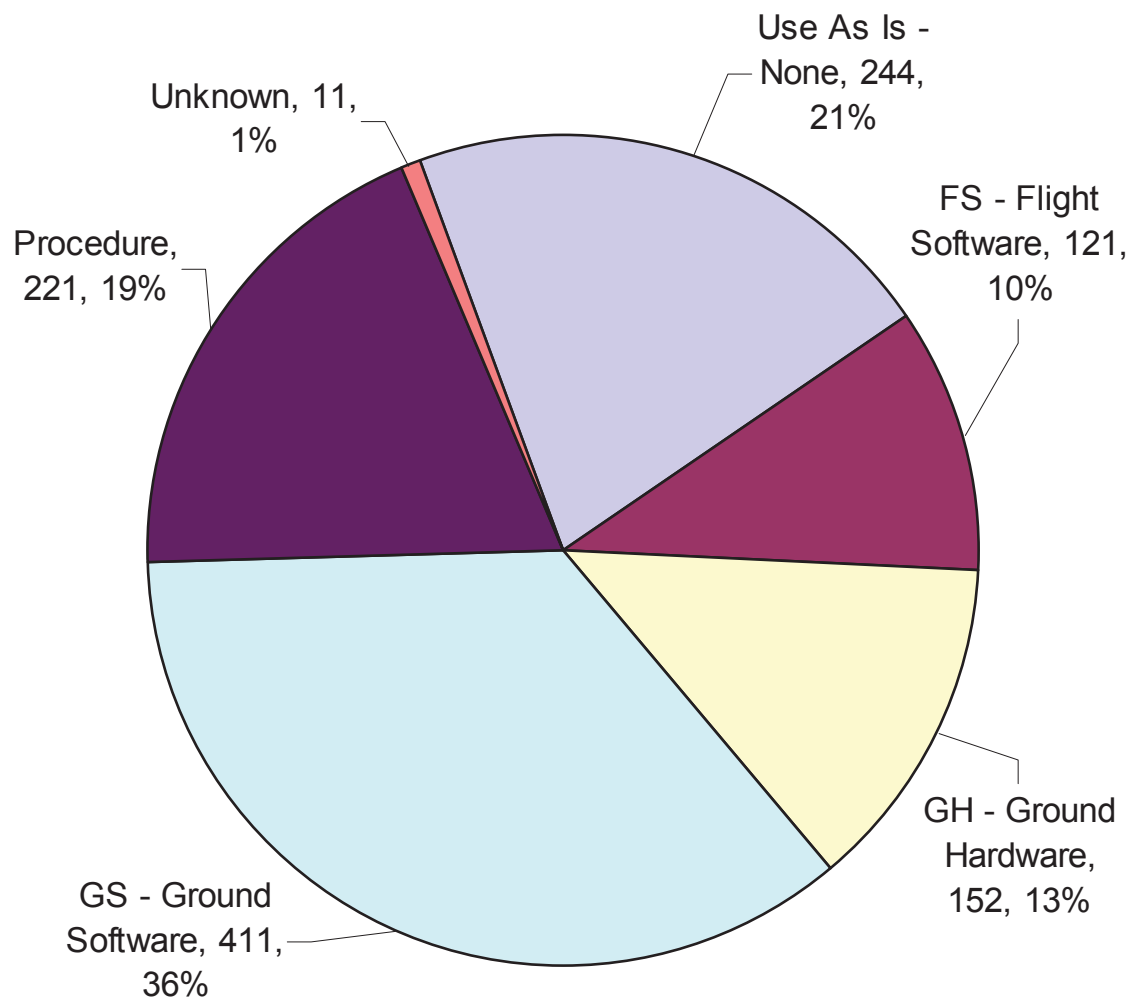
## Corrective Actions

- **“Use As Is”**
  - Essentially taking no action
- **Flight software**
  - Base software and uploaded commands
  - Fix hardware and software issues on board spacecraft
- **Ground software**
  - Earth based computers
- **Ground Hardware**
  - Changing Earth based hardware
    - Mission Control
    - Deep Space Network
- **Procedure**
  - Spacecraft operations
  - Mission team operations



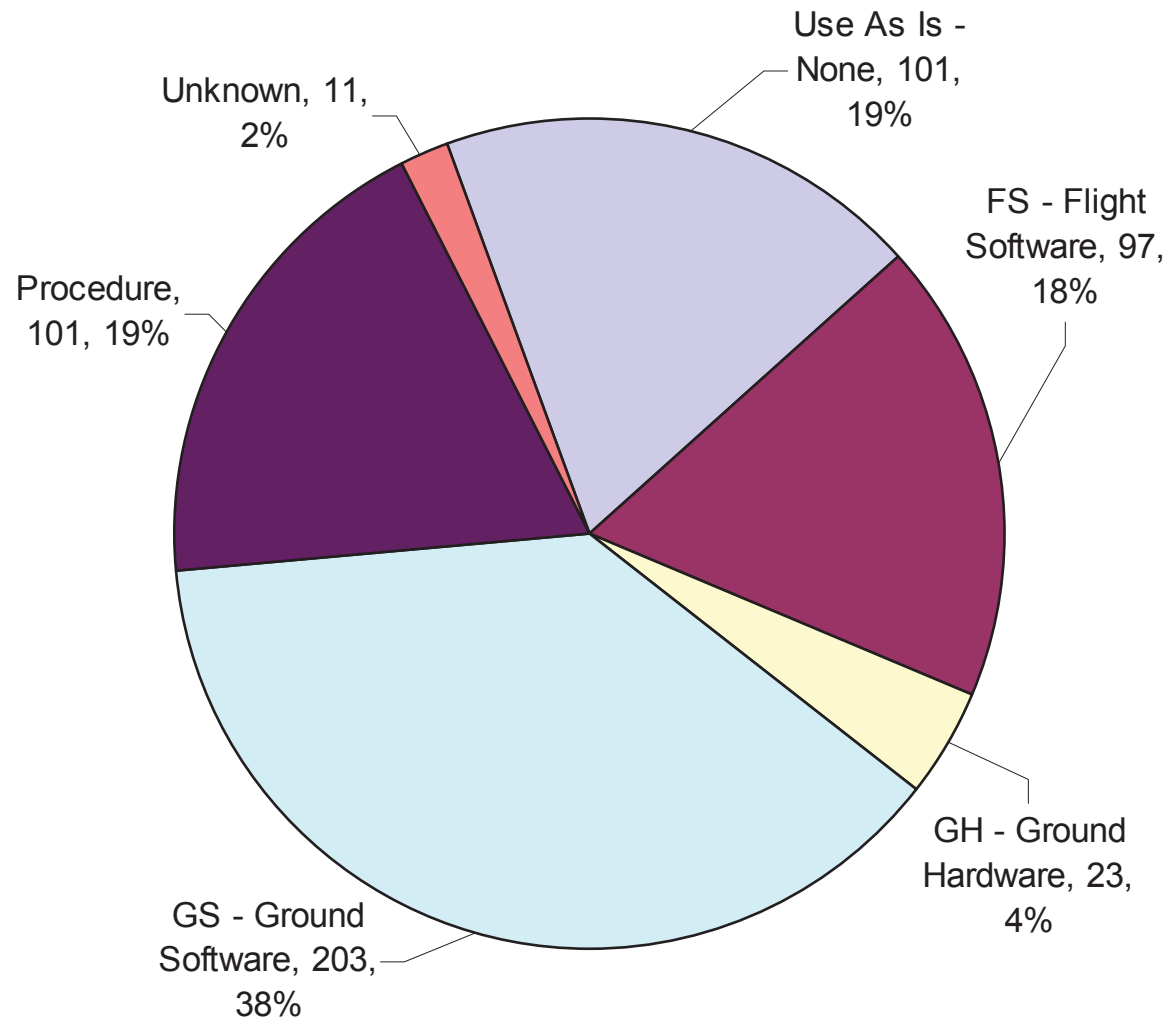


## Corrective Actions - MGS





## Corrective Actions - Odyssey

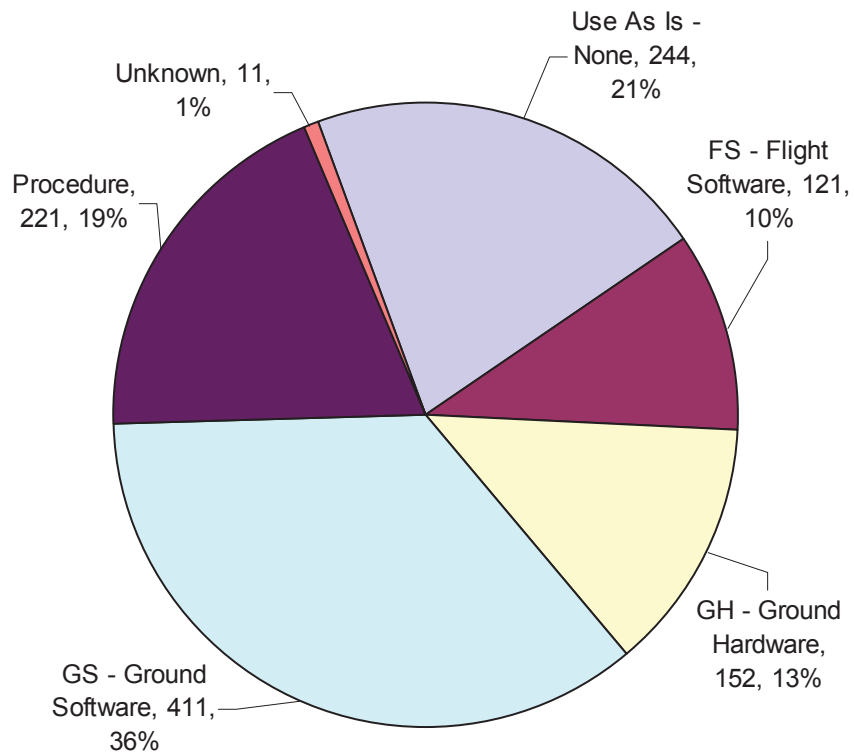




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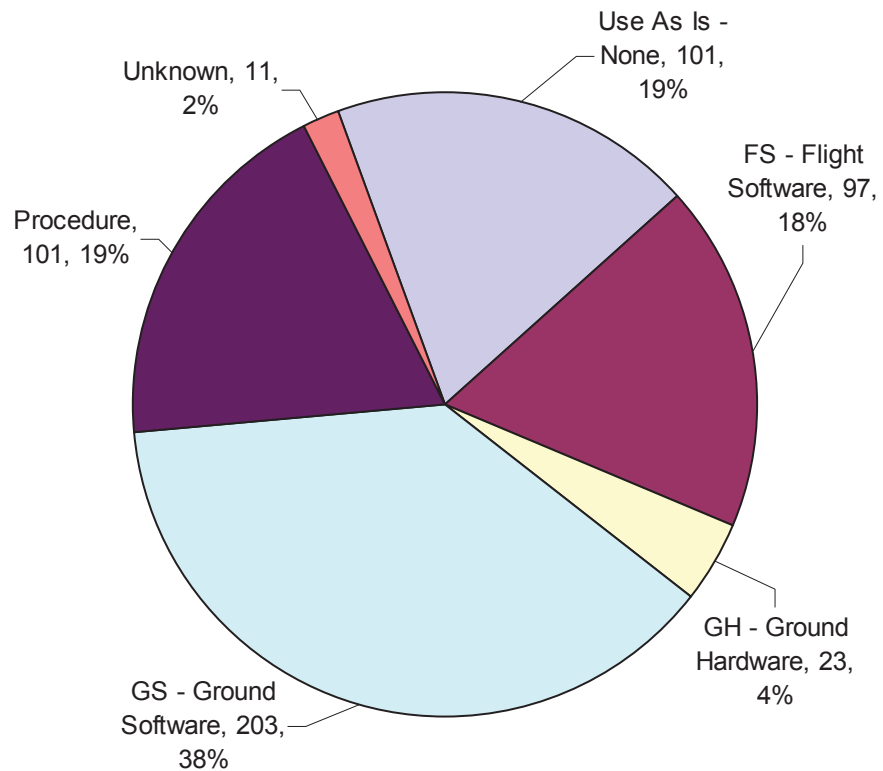
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## Corrective Actions



Mars Global Surveyor  
1996 – 2006 : 1160 ISAs

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Mars Odyssey  
2001 – April 2007 : 536 ISAs

27



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## Corrective Actions

- **Ground Software corrective actions are most common response**
  - Not surprising based on anomaly sources charts
  - Not a one-to-one match
- **“Use As Is” next most common**
  - Essentially to take no action
  - Used when nothing could or should be done
- **Procedure corrective action**
  - Much more common as a corrective action than as the source of an anomaly
    - Changes in how the mission teams work
    - Changes in approach to utilizing spacecraft



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## Corrective Actions

- **Flight Software corrective action**
  - Not the dominate response with either mission
  - Used for flight software issues
  - Sometimes used for flight hardware issues
- **Ground Hardware**
  - Generally least common response
  - Much more common on MGS than other missions
    - Issues with communication systems
    - Issues with computers

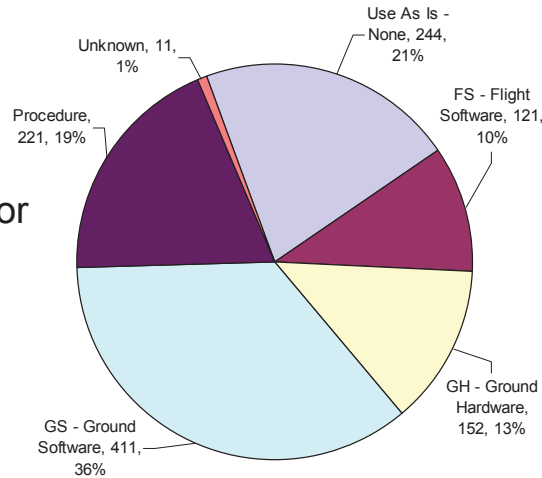


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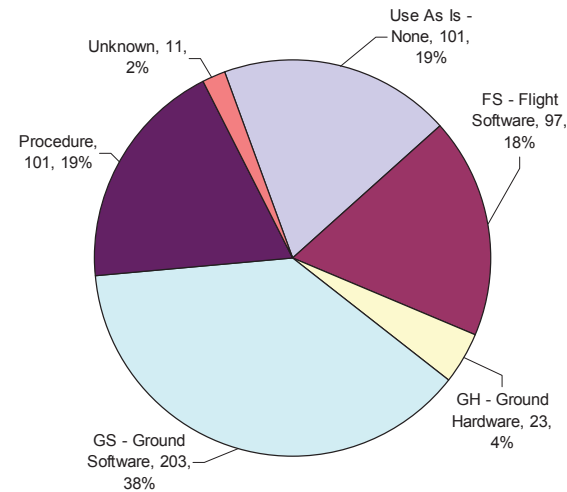
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## Corrective Actions – Four missions studied

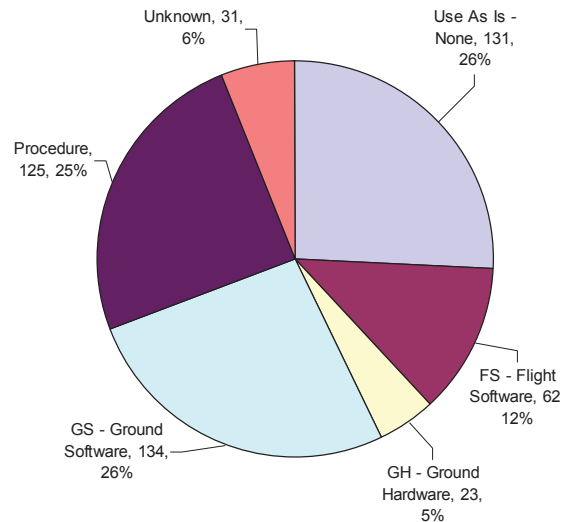
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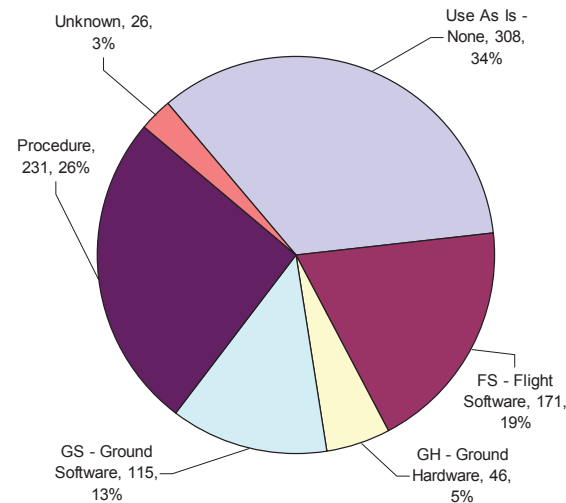
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## **Anomaly Sources and Corrective Actions**

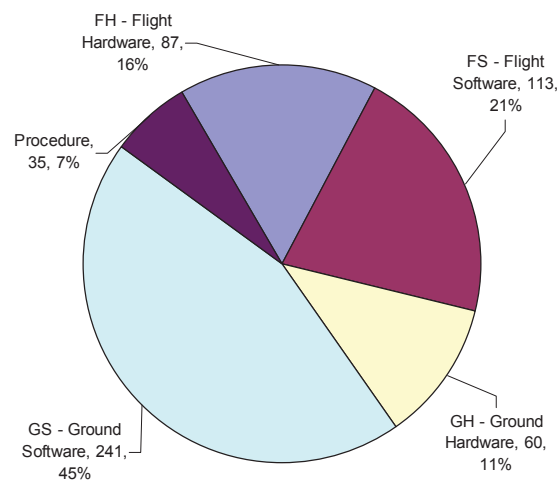
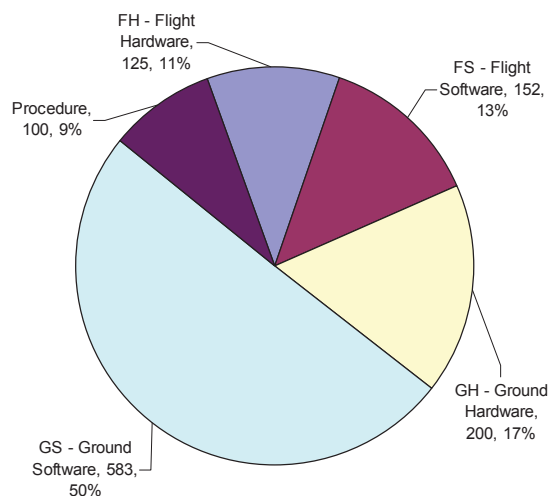
- **Corrective actions generally linked to anomaly sources**
  - Response is usually the of the same type as anomaly
  - Not a one-to-one relationship
- **Not possible with Flight Hardware anomalies**
  - Getting technician to spacecraft is slightly difficult when in flight
  - **Most common responses**
    - “Use As Is”
    - **Flight Software modification**
      - Includes modified operational sequences
    - **Procedure change**



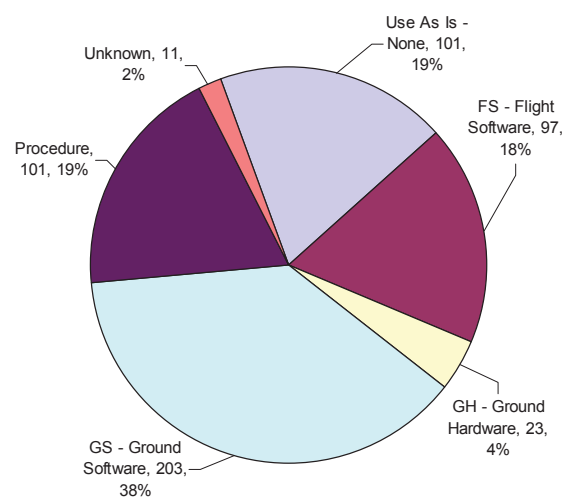
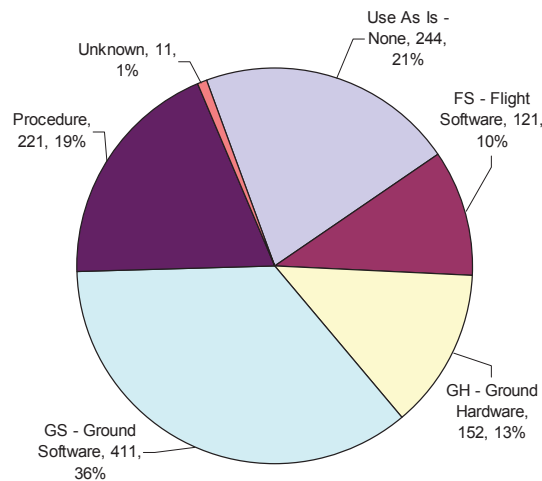


# Anomaly Sources and Corrective Actions

Anomaly Sources



Corrective Actions



Mars Global Surveyor  
1996 – 2006 : 1160 ISAs

Mars Odyssey  
2001 – April 2007 : 536 ISAs



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## Conclusion

- **Greatest number of anomalies occur early in mission**
  - Steep learning curve for mission teams
  - Working out kinks in spacecraft and systems
- **Peaks in anomalies with periods of high activity**
  - More attention given to mission
  - Anomalies may have greater impact on mission
- **Numbers of anomalies decrease with increasing mission time**
  - Fewer people on mission team
  - More familiarity with spacecraft and systems
  - Fewer instruments in operation (due to other failures?)



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## Conclusion

- **Ground software anomalies most common**
  - For missions within the last decade
  - Increased complexity and reliance on computer based systems
  - Other types of anomalies fairly equally distributed
- **Most anomalies from ground based systems**
  - 65% to 75%
    - Ground Software + Ground Hardware + Procedure
- **Corrective actions generally of same type as anomaly source**
  - Not always but as a general statement
  - Flight Hardware is the exception



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## Acknowledgements

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# Backup Slides



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# Anomaly Sources vs. Corrective actions Mars Global Surveyor

Anomaly Sources	Corrective Actions							totals
	Mission: Mars Global Surveyor	Use As Is None	FS - Flight Software	GH - Ground Hardware	GS - Ground Software	Procedure	Unknown	
	FH - Flight Hardware	49	52	0	2	22	0	125
	FS - Flight Software	39	66	0	12	35	0	152
	GH - Ground Hardware	30	0	110	41	16	3	200
	GS - Ground Software	110	0	42	355	68	8	583
	Procedure	16	3	0	1	80	0	100
	totals	244	121	152	411	221	11	1160



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# Anomaly Sources vs. Corrective actions Mars Odyssey

Anomaly Sources	Corrective Actions							totals
	Mission: Odyssey	Use As Is None	FS - Flight Software	GH - Ground Hardware	GS - Ground Software	Procedure	Unknown	
	FH - Flight Hardware	42	30	0	1	13	1	87
	FS - Flight Software	20	67	0	4	17	5	113
	GH - Ground Hardware	12	0	22	16	8	2	60
	GS - Ground Software	24	0	1	181	32	3	241
	Procedure	3	0	0	1	31	0	35
totals		101	97	23	203	101	11	536





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# Anomaly Sources vs. Corrective actions

## Mars Exploration Rovers – Surface Ops

Anomaly Sources	Corrective Actions							totals	
	Mission: MER surface totals	Use As Is None	FS - Flight Software	GH - Ground Hardware	GS - Ground Software	Procedure	Unknown		
	FH - Flight Hardware	48	20	0	4	45	6		123
	FS - Flight Software	39	42	0	9	25	6		121
	GH - Ground Hardware	2	0	21	3	1	1		28
	GS - Ground Software	37	0	2	114	14	14		181
	Procedure	5	0	0	4	40	4		53
totals		131	62	23	134	125	31	506	



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# Anomaly Sources vs. Corrective actions Galileo

Anomaly Sources	Corrective Actions							totals
	Mission: Galileo	Use As Is None	FS - Flight Software	GH - Ground Hardware	GS - Ground Software	Procedure	Unknown	
	FH - Flight Hardware	187	92	11	12	58	10	370
	FS - Flight Software	88	71	0	53	55	9	276
	GH - Ground Hardware	13	1	33	0	11	0	58
	GS - Ground Software	10	4	1	48	30	2	95
	Procedure	10	3	1	2	77	5	98
	totals	308	171	46	115	231	26	897